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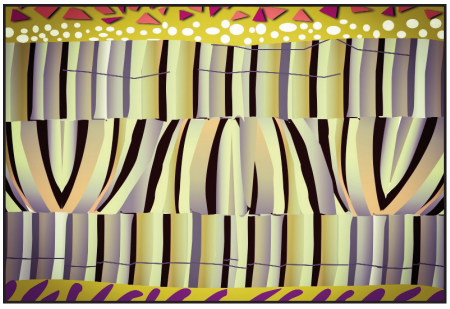

Igneous Rock Associations 15. The Columbia River Basalt Group: A Flood Basalt Province in the Pacific Northwest, USA

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SUMMARY

The middle Miocene Columbia River Basalt Group (CRBG) is the youngest, smallest, and best-preserved continental flood-basalt province on Earth. The CRBG covers ~ 210,000 km^2 of the Pacific Northwest, USA near the British Columbia border. CRBG consists of ~ 210,000 km^3 of basalt that began erupting ~ 16.7 Ma in the southern part of the province with younger eruptions progressively migrating northward; the last eruption occurred at ~ 5 Ma. The CRBG consists of seven formations. The Steens Basalt is the oldest but the next oldest, the Imnaha Basalt, began erupting near the end of the Steens volcanic episode. After a short hiatus at the end of the Imnaha Basalt, the Grande Ronde Basalt began to erupt. Both the Picture Gorge Basalt and Prineville Basalt erupted simultaneously with the Grande Ronde Basalt. The Steens, Imnaha, and Grande Ronde Basalts are the main phase of the eruptions representing ~ 94% of the CRBG volume. The Wanapum Basalt followed the Grande Ronde Basalt, which in turn was followed by the Saddle Mountains Basalt, the final phase of the eruptions. The formations, members and many flows of the CRBG can be identified by using a combination of major, minor and trace element compositions, lithology, magnetic polarity, and stratigraphic position. This allows the aerial extent and volume of the individual flows and groups of flows to be calculated and correlated with their respective dykes and vents. The eruption and emplacement rate of the flows has been controversial, with various lines of evidence suggesting that some flows erupted very rapidly and others probably erupted over much longer periods of time. The CRBG was probably derived from a mantle plume, although this conclusion is controversial. Compositions indicate the CRBG magmas underwent varying degrees of recharge, contamination, and fractionation prior to each eruption. Although the peak eruptions occurred during the middle Miocene Climatic Optimum, at present no significant extinction or environmental consequence has been correlated with the CRBG.

SOMMAIRE

Le Groupe de basaltes du fleuve Columbia (CRBG), du Miocène moyen, est la plus jeune, la plus petite et la mieux préservées des provinces de basaltes de plateau de la planète Terre. Le CRBG couvre une superficie d'environ 210 000 km^2 dans la portion nord-ouest des États-Unis du Pacifique près de la frontière avec la Colombie-Britannique. Le CRBG, c'est environ 210 000 km^3 de basaltes dont les premiers épanchements se sont produits il y a environ 16,7 Ma dans la portion sud de la province, les éruptions plus jeunes migrant progressivement vers le nord, la dernier s'étant produit il y a environ 5 Ma. Le CRBG est constitué de sept formations. La formation de basalte de Steens est le plus ancienne, mais la suivante, celle du basalte d'Imnaha est entrée en éruption près de la fin de l'épisode volcanique de Steens. Près une courte pause à la fin de l'épisode du basalte de la formation d'Imnaha, l'éruption du basalte de Grande Ronde a commencé. Et le basalte de Picture Gorge et le basalte de Prineville ont fait éruption en même temps que le basalte de Grande Ronde. Les basaltes de Steens, d'Imnaha, et de Grande Ronde forment la principale portion des éruptions avec environ 94 % du volume du CRBG. Le basalte de Wanapum a succédé au basalte de la Grande Ronde, puis ce fut le basalte de Saddle Mountains, la phase finale des éruptions. Les formations, les membres et le nombre de coulées du CRBG peuvent être définis par analyse de leur composition en éléments majeurs, mineurs et traces, leur lithologie, leur polarité magnétique, et leur position stratigraphique. Ce qui permet d'es-

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timer l'étendue et le volume de coulées individuelles, de groupes de coulées, et de les relier avec leur cheminée et dikes respectifs. Le taux des flux éruptifs ainsi que le leur mise en place ont été sujet à controverse étant donné que certaines indications suggèrent que certaines éruptions ont été très rapides alors que d'autres se seraient produites sur des périodes beaucoup plus longues. Le CRGB est probablement issus d'un panache mantellique, mais cela demeure controversé. Les compositions relevées indiquent que les magmas du CRBG ont subi à des degrés divers, des recharges, des contaminations et du fractionnement par cristallisation avant chaque éruption. Bien que les plus fortes éruptions se soient produites durant la période climatique optimum du Miocène moyen, jusqu'à présent, aucune extinction significative ou répercussion environnementale ont été mises en corrélation avec le CRBG.

INTRODUCTION

The Columbia River Flood Basalt Province (CRFBP) in the Pacific Northwest of the United States is the youngest and best-preserved continental large igneous province (LIP) on Earth. The Columbia River Basalt Group (CRBG) is a series of generally tholeiitic basalt to basaltic andesite with sparse alkali-olivine basalt that erupted between ~ 16.7–5.5 Ma (Jarboe et al. 2008; Barry et al. 2013) and cover more than 210,000 km^2 of Washington, Oregon, Idaho and Nevada (Fig. 1; Reidel et al. 2013a). They form part of a larger volcanic region that includes the Chilcotin Plateau Basalts of British Columbia, the contemporaneous silicic centres in northern Nevada, the basaltic and time-transgressive rhyolitic volcanic fields of the Snake River Plain and Yellowstone Plateau, and the High Lava Plains of central Oregon (Camp et al. 2003). Although the province is the smallest LIP on Earth, its location in the easily accessible Pacific Northwest has allowed the stratigraphy and structure to be refined by many decades of detailed fieldwork, combined with geochemical, geochronological, and paleomagnetic studies. Thus, the CRBG has become a model for the study of similar provinces worldwide.

This paper reviews the current status of the CRBG focusing on the stratigraphic framework, the areal extent and volume of the lava flows, their eruptive history, mode of lava flow emplacement, current thoughts on the petrogenesis of the basalt, and finally the impact of these lavas on the Miocene environment.

REGIONAL SETTING

The CRBG erupted in a back-arc setting between the Cascade volcanic arc and the Rocky Mountains (Fig. 1). The flood-basalt lavas cover basement rocks that record a long and complex geologic history beginning in the Proterozoic with the breakup of the supercontinent Rodinia, followed by the suturing of Mesozoic accreted terranes, and deposition and deformation of Paleogene and Neogene sedimentary and volcanic rocks. These basement structures became the template for geologic structures now superimposed on the basalt province (Reidel et al. 2013b).

Rocks older than the CRBG are exposed around the margins of the flood-basalt province and have been penetrated in deep boreholes in the Columbia Basin. In the southernmost part of the province, Mesozoic accreted terrane rocks and Paleogene and Neogene volcanic rocks are exposed in the footwalls of Basin-and-Range faults. To the northeast and east, the CRBG laps onto an assemblage of Proterozoic, lower Paleozoic and Jurassic rocks, and Cretaceous intrusions of the Idaho Batholith (Stoffel et al. 1991; Reidel et al. 2013b). Within and south of the Blue Mountains, the CRBG overlies Paleogene and Neogene volcanic rocks and related volcaniclastic rocks partly assigned to the Clarno and John Day formations. These, in turn, overlie northeast-trending belts of Permian to Cretaceous accreted terranes of intra arc- and volcanic arc-origin (Walker and MacLeod 1991; Schwartz et al. 2010; LaMaskin et al. 2011).

The Cascade volcanic arc forms the western margin of the CRFBP. CRBG flows were able to cross the Miocene Cascade volcanic arc through a major east-northeast-trending lowland structural gap, the Columbia Trans-arc Lowland (Fig.1; Beeson et al. 1979), where they spread across much of the northern Willamette Valley region, and through the Coast Range, eventually reaching the Pacific Ocean where they continued to advance onto the continental shelf (Beeson et al. 1979; Niem and Niem 1985).

The area covered by the CRBG is divided by the Blue Mountains into the Oregon Plateau and the Columbia Basin (Fig. 1) based on significant differences in the style of post-CRBG deformation. The Oregon Plateau contains four structural-tectonic regions: (1) the northern Basin and Range, (2) the High Lava Plains, (3) the Owyhee Plateau, and (4) the Oregon-Idaho graben. The Columbia Basin covers a broader region and consists mainly of the Yakima Fold Belt and the Palouse Slope.

STRATIGRAPHIC FRAMEWORK OF THE COLUMBIA RIVER BASALT GROUP

The CRBG (Figs. 2, 3, and 4) is a thick sequence of more than 350 mainly continental tholeiitic flood-basalt flows that were erupted over an 11 million year period (Swanson et al. 1979; Tolan et al. 1989; Jarboe et al. 2008; Barry et al. 2013) and have an estimated volume of about 210,000 km^3 (Fig. 2). The main eruptive phase of the basalt includes the Steens Basalt, the Imnaha Basalt and Grande Ronde Basalt when 94% of the basalt erupted in ~ 1 million years. The peak of CRBG eruptions occurred during Grande Ronde time, when ~ 74% of the flood-basalt volume was generated in only ~ 400,000 years or less (~ 16–15.6 Ma; Jarboe et al. 2008; Barry et al. 2010, 2013). The waning phase (~ 7%) includes the Wanapum Basalt and Saddle Mountains Basalt that erupted over 10 million years. The Picture Gorge and Prineville Basalts are much smaller in volume and were coeval with the Grande Ronde Basalt. The contribution of each of the seven formations is: Steens Basalt - ~ 15.2%; Imnaha Basalt - ~ 5.3%; Grande Ronde Basalt - ~ 72%; Picture Gorge Basalt - ~ 1.1%; Prineville Basalt - ~ 0.3%; Wanapum Basalt - ~ 5.8%; and Saddle Mountains Basalt - ~ 1.1%.

Volcanism began in the Oregon Plateau and quickly spread north to the Columbia Basin (Camp and Ross 2004). In the Oregon Plateau,